

VECTOR SCATTER INSTRUCTION CONTROL CIRCUIT AND  
VECTOR ARCHITECTURE INFORMATION PROCESSING  
EQUIPMENT

[0001]

5 FIELD OF THE INVENTION

The present invention relates to a vector architecture information processing equipment, and more particularly to a vector scatter instruction control circuit.

[0002]

10 BACKGROUND OF THE INVENTION

On a vector architecture information processing equipment, memory area data accessed by a vector instruction is not usually entered in a cache.

[0003]

15 The reason is that locality of reference generally does not well applies to data access by a vector instruction so that data accessed by a vector instruction, if entered in a cache memory, is swapped out immediately by other cache line data, and a cache hit ratio decreases.

[0004]

20 Also, on a vector architecture information processing equipment, there are provided some vector based memory access instructions, such as VST (vector store) /VLD (vector load) instruction in which a memory access address is defined by a start address and a distance of a vector data to be accessed.

25 [0005]

VLD instruction loads data from memory into a vector data storage area made of a plurality of words arranged in a vector unit, called "vector register" in accordance with memory access address defined as described above.

5 [0006]

Conversely, VST instruction stores data from a register into memory.

[0007]

10 In case of VST instruction, an address accessed by the instruction may be determined on an instruction issue stage. It is relatively easy to accomplish an improvement of performance, by controlling such an instruction as VLD instruction or scalar load instruction that follows VST instruction to be executed ahead of the VST instruction.

15 [0008]

On the other hand, with so-called "list vector" instructions, such as VGT (vector gather)/VSC (vector scatter) instructions, data stored in vector registers arranged in the vector unit is used as a memory address to be accessed so that the memory address to be accessed is  
20 identified only after the instruction gets to the vector unit, whereas the address is generally random.

[0009]

For the sake of better understanding of the present invention, a list vector instruction will be described with reference to FIG. 8.

25 [0010]

First, as shown in FIG. 8(a), VGT (vector gather) instruction loads data from memory in such a way that a memory data at an address VA (n) of a vector register Vy, is loaded into a corresponding element of the vector register Vx.

5 [0011]

As shown in FIG. 8(b), VSC (vector scatter) instruction stores data into memory in such a way that data of the vector register Vx is stored into a memory area of which address VA (n) is stored in a corresponding element of the vector register Vy.

10 [0012]

In contrast to vector memory access instructions, with a scalar memory access instruction, locality of reference generally applies to data accesses, as a result of which, such a system is usually adopted in which data accessed by the scalar memory access instruction is stored in a cache memory to make memory access latency being hidden.

15 [0013]

## SUMMARY OF THE INVENTION

When a vector memory access instruction is issued to write data into memory on a vector architecture information processing equipment accommodated with a cache as described in the above, it is necessary to execute cache invalidation to ensure cache consistency in case that an address to be accessed is being entered in the cache, wherein the cache invalidation process generates a stall of a cache access instruction that follows the vector memory access instruction, which is a one of primary causes of degradation of performance.

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[0014]

A cache invalidation process differs between VST (vector store) instruction and VSC (vector scatter) instruction.

[0015]

5 In case of VST instruction, a start address and a distance are determined when the instruction is issued so that with these two data relatively high-speed cache invalidation is realized. Furthermore, since memory access start address and end address of VST instruction can be calculated promptly, a scalar LD (load) instruction that follows VST  
10 instruction, may be controlled to be executed ahead of the VST instruction if no address coincidence is detected between these two instructions.

[0016]

On the other hand, in case of VSC (vector scatter) instruction,  
15 since an address to be accessed is determined only after the address is read from a vector register and, in addition, the address value is random, it is necessary to send an invalidation address from a vector unit to a cache invalidation control unit (see 4 in FIG. 1) in a scalar unit to invalidate cache data that matches the invalidation address.

20 [0017]

As a result, all memory access instructions that follow VSC instruction cannot be issued until this cache invalidation processing is completed. This causes degradation of performance.

[0018]

25 This problem will be described more in detail with reference to

FIGS. 6 and 7.

[0019]

First, in order to make description easy to understand, LDS instruction, which belongs to scalar load (cache access) instructions, will be described with reference to FIG. 7. As with VGT/VSC instruction, LDS instruction comprises four fields: OPC (operation code) and operands X, Y, and Z wherein a memory access address is calculated as  $R_y + R_z$  and a resultant data M ( $R_y + R_z$ ) that is read from memory area of an address  $R_y + R_z$  is stored into register  $R_x$ .

10 [0020]

In FIG. 6(a), after VST (vector) instruction is issued, the cache is invalidated and, almost at the same time, data is written from the vector into memory.

[0021]

15 The LDS instruction following the VST instruction may be issued even with the cache being invalidated, unless access address of the LDS instruction overlaps with that of the VST instruction.

[0022]

On the other hand, referring to FIG. 6(b), with VSC (vector scatter) instruction, cache invalidation is performed when vector processing starts and an invalidating address is sent. In addition, since an address to be accessed immediately after VSC instruction is issued is not known and an address is random, LDS instruction that follows the VSC instruction is kept waiting in a hold state until cache invalidation is  
20 completed.  
25

[0023]

As described above, all memory access instructions that follow the VSC instruction cannot be issued before cache invalidation is completed and this causes performance degradation.

5 [0024]

In view of the foregoing, it is an object of the present invention to provide a vector architecture processing equipment that prevents a following instruction from being delayed because of cache invalidation of a vector scatter instruction and that executes the following instruction before the vector scatter instruction to improve performance.

10 [0025]

To achieve the above object, in accordance with one aspect of the present invention is provided a circuit comprising:

means for detecting whether an overlap exists between an address to be accessed by an area-specified vector scatter instruction, which specifies a range of memory access address, and an address to be accessed by a memory access instruction that follows the area-specified vector scatter instruction; and

15 means for holding the memory access instruction that follows on which address coincidence is detected.

In accordance with one aspect of the present invention is provided a circuit for controlling vector scatter instruction wherein an area-specified vector scatter instruction specifying scattered areas is provided as an instruction set, comprising:

25 an address coincidence detection unit detecting if an address to

be accessed by the area-specified vector scatter instruction overlaps with an address to be accessed by a memory access instruction that follows the vector scatter instruction; and

a hold control unit holding the memory access instruction that  
5 follows the vector scatter instruction if the addresses overlap.

In accordance with another aspect, is provided a vector architecture information processing equipment comprising:

a vector scatter address coincidence detection unit including:

registers for storing an area start address and an area end  
10 address of an area-specified vector scatter instruction in which the area start address and the area end address are specified; and

a circuit for checking if an address to be accessed by a memory  
access instruction following the area-specified vector scatter instruction  
is within a scatter area defined by the area start address and the area end  
15 address specified by the area-specified vector scatter instruction to  
outputs an address conflict signal if the address to be accessed by the  
following memory access instruction is within the scatter area, wherein  
an instruction issue control unit comprises a hold control circuit for  
holding said following memory access instruction upon receipt of an  
20 address coincidence signal emitted from said vector scatter address  
coincidence detection unit.

In accordance with another aspect, the present invention provides a vector architecture information processing equipment comprising:

25 an instruction issue control unit decoding an instruction data to

direct an instruction operation;

a cache control unit receiving an address from said instruction issue control unit to control a cache;

a vector unit, on receipt of an execution directive when a vector instruction is issued from said instruction issue control unit sending write vector data to a memory and sending a cache invalidation address, if the vector instruction is an area-specified vector scatter instruction specifying an area start address and an area end address of a scatter area;

a cache invalidation control unit receiving the cache invalidation address from said vector unit to invalidate the cache; and

a vector scatter address conflict detection unit, on receipt of the area start address and the area end address of the area-specified vector scatter instruction from a register block accessed by said instruction issue control unit when the area-specified vector scatter instruction is issued from said instruction issue control unit,

detecting if an area specified by the area start address and the area end address overlaps with an address area to be accessed by a memory access instruction following the area-specified vector scatter instruction to activate an address coincidence signal for sending said signal to said instruction issue control unit if an address overlap is detected,

wherein said instruction issue control unit comprises a hold control circuit that holds the following memory access instruction in response to the activated address conflict signal from said vector scatter



address conflict detector.

The hold control circuit preferably does not hold the following memory access instruction if the address coincidence signal from said vector scatter address coincidence detection unit is inactive. The hold  
 5 control circuit holds the following memory access instruction until a cache invalidation end notification is received from said cache invalidation control unit.

The vector scatter address coincidence detection unit preferably comprises:

10 a first comparator that compares the address to be accessed by the following memory access instruction with the area start address specified by the area-specified vector scatter instruction and, if the address to be accessed by the following memory access instruction is equal to or larger than the area start address, outputs an active signal;

15 a second comparator that compares the address to be accessed by the following memory access instruction with the area end address specified by the area-specified vector scatter instruction and, if the address to be accessed by the following memory access instruction is equal to or smaller than the area end address, outputs an active signal;  
 20 and

a logical circuit that activates the address conflict signal and outputs the signal if both output signals from said first comparator and the output from said second comparator are active.

In an operand of the area-specified vector scatter instruction is  
 25 included a predetermined field for specifying two registers in which the

scatter area start address and the scatter area end address are respectively specified, said two registers being included in said register block.

Still other objects and advantages of the present invention will become readily apparent to those skilled in this art from the following detailed description, wherein only the preferred embodiment of the invention is shown and described, simply by way of illustration of the best mode contemplated of carrying out this invention. As will be realized, the invention is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects, all without departing from the invention. Accordingly, the drawing and description are to be regarded as illustrative in nature, and not as restrictive.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing a configuration of an embodiment of the present invention.

FIG. 2 is a diagram showing a configuration of an instruction issue control unit and a VSC address conflict detector in the embodiment of the present invention.

FIG. 3 is a diagram showing VSC instruction in the embodiment of the present invention.

FIG. 4 is a diagram showing an operation of the embodiment of the present invention.

FIG. 5 is a diagram showing an operation of the embodiment of the present invention.

*In A1*  
~~FIG. 6 is a diagram showing a processing of VSC instruction~~  
~~and following LDS instruction.~~ *A1*

FIG. 7 is a diagram showing a processing of LDS instruction.

*In A2*  
~~FIG. 8 is a diagram showing conventional VGT instruction~~  
~~and VSC instruction.~~ *A2*

[0026]

## PREFERRED EMBODIMENTS OF THE INVENTION

An embodiment of the present invention will now be described.

*FIG. 8*  
 An embodiment of the present invention comprises a vector scatter  
 10 (VSC) address coincidence detection unit that comprises a plurality of  
 registers in which an area start address and an area end address of an  
 area specified by an area-specified vector scatter instruction are stored;  
 and a circuit that detects if memory address specified by the area-  
 specified vector scatter instruction overlaps with memory address to be  
 15 accessed by a memory access instruction following the area-specified  
 vector scatter instruction, wherein an instruction issue control unit  
 comprises a hold control circuit that holds a following memory access  
 instruction that specifies memory address coincides with address  
 specified by the area-specified vector scatter instruction.

20 [0027]

More specifically, in a preferred embodiment of the present  
 invention, a vector architecture information processing equipment  
 comprises:

an instruction issue control unit (1) that decodes instruction  
 25 data and directs an instruction operation;

a cache control unit (2) that receives an address from the instruction issue control unit (1) for controlling a cache (for example, cache update for scalar memory access instructions);

5 a vector unit (6) that receives an execution directive when a vector instruction is issued from the instruction issue control unit (1) and, if the vector instruction is an area-specified VSC instruction (vector scatter instruction) specifying an area start address and an area end address of a scatter area, sends vector data to be stored onto a memory (7) and, at the same time, sends a cache invalidation address;

10 a cache invalidation control unit (4) that receives the cache invalidation address from the vector unit (6) for invalidating the cache; and

a VSC address conflict detection unit (3) that receives the area start address and the area end address specified by the area-specified VSC instruction from a register block (5) when the area-specified VSC instruction is issued from the instruction issue control unit (1), detects if an area specified by the area start and end addresses overlaps with an address area to be accessed by a memory access instruction following the area-specified VSC instruction, activates an address conflict signal  
15 if an address overlap is detected, and sends the signal to the instruction  
20 issue control unit (1).

The instruction issue control unit (1) comprises a hold control circuit (105 in FIG. 2) that holds the following memory access instruction in response to the activated address conflict signal from the  
25 VSC address conflict detection unit (3).

[0028]

According to the present invention, the area-specified VSC instruction has an op-code and X, Y, and Z fields, where two registers from a register block are specified for the Z field and a start address and  
5 an end address of a scatter area are respectively specified in these two registers.

[0029]

The embodiment of the present invention will be described more in detail, using an example with reference to the drawings. FIG. 1,  
10 illustrates a basic configuration of one embodiment of the present invention.

[0030]

Referring to FIG. 1, a vector machine of the embodiment of the present invention comprises a scalar processor, a vector unit 6, and a  
15 memory 7. The scalar processor comprises an instruction issue control unit 1, a register block 5, a cache control unit 2, a VSC address coincidence detection unit 3, and a cache invalidation control unit 4.

[0031]

The instruction issue control unit 1 decodes instruction data  
20 read from the memory 7 via a signal line 71 to request instruction execution.

[0032]

The instruction issue control unit 1 sends an address to the cache control unit 2 and the VSC (vector scatter instruction) address  
25 coincidence detection unit 3 via a signal line 12, wherein the cache

control unit 2 and the VSC address coincidence detection unit 3 both receiving the address, execute controlling cache access and checking VSC address coincidence respectively.

[0033]

5           The instruction issue control unit 1 controls read form and write to the register block 5 respectively via signal lines 15 and 51.

[0034]

10           If scalar loading from the instruction issue control unit 1 misses , the cache control unit 2 requests cache refill data via a signal line 27 and receives the data from the memory 7 via a signal line 72.

[0035]

15           When a scalar store instruction is issued, a cache control by the cache control unit 2 is performed based on store-through algorithm, whereon in case that a cache hit occurs the cache control unit 2 rewrites cache data and always writes the data in the memory 7.

[0036]

20           When a vector instruction is issued, the instruction issue control unit 1 sends an execution directive to the vector unit 6 via a signal line 16. At this time, in case that the vector instruction is VSC instruction, the vector unit 6 sends vector data to be written to the memory 7 via a signal line 67. In addition, the vector unit 6 sends a cache invalidation address to the cache invalidation control unit 4 via a signal line 64.

[0037]

25           In addition, when a VSC instruction is issued, a start address

and end address of the VSC instruction are sent from the register block 5 to the VSC address coincidence detection unit 3 via a signal line 53. The VSC address coincidence detection unit 3 checks if an address area specified by the instruction overlaps with that specified by a following memory access instruction to send an address coincidence signal to the instruction issue control unit 1 via a signal line 31 in case that an address overlap is detected.

[0038]

Next, specifications of an area-specified VSC instruction proposed newly by the present invention will be described with reference to FIG. 3.

[0039]

As shown in FIG. 3, instruction field of the area-specified VSC instruction is divided into four as described above: OPC (operation code), X, Y, and Z. The area-specified VSC instruction differs from the normal VSC instruction in that the Z field specifies two registers in the register block 5,  $R_n$  and  $R_{n+1}$ , which respectively specify a start address and an end address of a scatter area. The X and Y fields of the VSC instruction are respectively used to specify the number of a vector register in the vector unit 6.

[0040]

FIG. 2 illustrates a configuration of the instruction issue control unit 1, the register block 5, and the VSC address coincidence detection unit 3 of the embodiment of the present invention.

[0041]

Referring to FIG. 2, instruction data supplied via the signal line 71 is once stored in an instruction cache 101 and then stored in the four fields, OPC (instruction code), X, Y and Z, of a D stage register 102.

5 [0042]

After that, the instruction code, X field, and Y field are moved to an EE stage register 103. At the same time, the operand data is read from a register 50 of the register block 5 into registers Y data ee and Z data ee in the EE stage register 103.

10 [0043]

In the case of LDS instruction, information in the EE stage register 103 is moved to an EC stage register 104 that follows. At the same time, an address calculated by an AAD (address adder) 115 are stored in an address ec (register) for use in accessing the cache. The output of the address ec (register) is supplied to the cache control unit 2 as the address signal 12 in FIG. 1 and to the VSC address coincidence detection unit 3.

[0044]

In the case of the area-specified VSC instruction newly provided by the present invention, VSC start address and end address read via the Z data ee (latch) in the EE stage are stored, respectively, in VSC start address ec and VSC end address ec in the EC stage. Note that a signal H supplied from an HLD (hold) control unit 105 to the VSC start address ec and the VSC end address ec, is a signal used to direct the VSC start address ec and the VSC end address ec to hold data.

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[0045]

After that, data held in the VSC start address ec and the VSC end address ec, strobed by the a VSC issue signal 13 from the HLD control unit 105, is set in the VSC start address eb (latch) and the VSC  
5 end address eb (latch) in the EB stage.

[0046]

The information is retained until the next area-specified VSC instruction is issued.

[0047]

10 The VSC address coincidence detection unit 3 comprises a comparator 301, a comparator 302, and a logical product circuit 303. The comparator 301 compares a value of the address ec that latches an access address of a memory access instruction that follows with a value of the VSC start address eb to output an activated output signal, if the  
15 address to be accessed by the following memory access instruction is equal to or larger than the VSC start address. The comparator 302 compares a value of the address ec with a value of the VSC end address eb to outputs an activated output signal, if the address to be accessed by the following memory access instruction is equal to or smaller than the  
20 VSC end address. When both output signals supplied from the comparator 301 and the comparator 302 are active, the logical product circuit 303 provides an activated address coincidence signal 31 to the HLD control unit 105.

[0048]

25 If the address to be accessed by the following LDS instruction

that is issued immediately following the area-specified VSC instruction overlaps with the scatter area of the VSC instruction, the VSC address coincidence signal 31 is activated and sent to the HLD control unit 105. In response to this signal, the HLD control unit 105 activates (turns on) the ECHLD signal. This signal remains in an activated state (on state) until a cache invalidation end signal 41 output from the cache invalidation control unit 4 is turned on (until cache invalidation processing is completed). The following LDS instruction is held in the EC stage of the instruction issue control unit 1.

10 [0049]

If the LDS instruction being kept waiting in the EC stage is followed by another instruction, the HLD control unit 105 turns on the EEHLD signal or the DHLD signal to keep the following instruction waiting in the EE stage or in the D stage.

15 [0050]

A register update control unit 111 shown in FIG. 2 controls update of the register 50 in the register block 5, for example, controls an avoidance of known WAW (write after write) hazard. In case of VSC instruction, an output from the X/Y ec of the EC stage register 104 indicates a vector register number, which is supplied to the vector unit 6 via the signal line 16.

[0051]

Next, operation timings of the area-specified VSC instruction and immediately following LDS instruction in the embodiment of the present invention will be described with reference to FIGS. 4 and 5. In

25

those two examples, it is assumed that a cache hit occurs on the following LDS instruction.

[0052]

FIG. 4 illustrates a timing operation when an area (scatter area) specified by the area-specified VSC instruction does not overlap with an address to be accessed by the immediately following LDS instruction, that is, when an address coincidence does not occur. Note that, in FIGS. 4 and 5, DD, EE, EC, and EB correspond respectively to the D stage, EE stage, EC stage, and EB stage (VSC start address eb, VSC end address eb) in the instruction issue control unit 1 shown in FIG. 2.

[0053]

The area-specified VSC instruction, which must read registers twice ( $R_n$  and  $R_{n+1}$ ) specified in the Z operand ( $Z_d$ ), is divided into two (VSC1st and VSC2nd in FIG. 4) in the D stage. A increment circuit (+1) is a control circuit for reading the registers twice ( $R_n$  and  $R_{n+1}$ ).

[0054]

In timing 3 and 4, the VSC instruction issue signal 13 is asserted. At this time, the start address and the end address are stored, respectively, in the VSC start address eb and the VSC end address eb.

[0055]

After that, when the LDS instruction is issued in timing 5 in the EC stage, cache data is read in timing 6 and the cache data is stored into a WDR (write data register) in register block 5 in timing 7. In timing 8, contents of the WDR are written in the register 50 to finish an execution of the LDS instruction. WAR in the register block 5 is a write

address register that is used to select a register from a plurality of registers in the register 50 (register file).

[0056]

Next, with reference to FIG. 5, an description is done  
5 concerning an operation performed when an area specified by the VSC instruction overlaps with an address to be accessed by the following LDS instruction, that is, an operation performed when an address coincidence occurs. Difference between an operation shown in FIG.5 and that shown in FIG. 4 begin to appear from timing 5 at which the  
10 signal indicating that VSC addresses coincidence signal is turned on in FIG.5.

[0057]

After that, the LDS instruction is held in the EC stage with the ECHLD signal being kept in a on state until the cache invalidation end  
15 signal 41 is turned on in timing 7.

[0058]

Then, as in case that address does not coincide, a result of the LDS instruction is written on the register 50 via the WDR in the register block 5.

20 [0059]

In the embodiment of the present invention, the instruction control circuit obtains information on the memory area to be accessed by the area-specified VSC instruction from a programmer (that is, from a program coded by the programmer). This allows LDS instruction that  
25 follows to be executed ahead of the area-specified VSC instruction, as a

result of which significantly improves performance. A effect of the embodiment of the present invention will be described more in detail with reference to FIG. 6.

[0060]

5 First, with a VST instruction, an area to be accessed is determined at an instruction issue time. Therefore, the cache may be invalidated immediately to allow following LDS instruction to be executed ahead of the VST instruction. If it is found that the following instruction may be executed before the preceding instruction, the LDS  
10 instruction may be executed even on a period on which cache invalidation is under way.

[0061]

On the other hand, in a conventional vector machine, since memory area to be accessed by VSC instruction is not determined when  
15 the instruction is issued and in addition, is random, LDS instruction that follows cannot be executed before the VSC instruction and must be delayed until cache invalidation is completed.

[0062]

With the present invention, it is possible to control LDS  
20 instruction that follows to be executed ahead of the preceding VSC instruction as if the VSC instruction was a VST instruction.

[0063]

With the conventional vector data processing unit, it is necessary for the following LDS instruction, an access address of which  
25 is arbitrary one, to wait from issue time of the VSC instruction to a time

of completion of cache invalidation process.

[0064]

On the other hand, in accordance with the present invention this wait time is eliminated when no address coincidence occurs, as a  
5 result of which significantly improves performance of LDS instruction that is issued with a extremely high frequency.

[0065]

The meritorious effects of the present invention are summarized as follows.

10 As described above, with the present invention, by acquiring information on areas to be accessed by an area-specified VSC (vector scatter) instruction from a program, LDS instruction that follows the area-specified VSC instruction may be executed before the area-specified VSC instruction to improve significantly processing  
15 performance. The reason is that the data processing unit according to the present invention provides means for detecting whether a address coincidence occurs between an address to be accessed by the VSC instruction, which specifies scattered areas, and an address to be accessed by the following instruction and means for holding the  
20 following memory access instruction when an address conflict occurs.

It should be noted that other objects, features and aspects of the present invention will become apparent in the entire disclosure and that modifications may be done without departing the gist and scope of the present invention as disclosed herein and claimed as appended  
25 herewith.

[illegible]